SAE TECHNICAL PAPER SERIES

2000-01-2573

Noise and Emission Reduction Strategies for a Snowmobile

Scott A. Miers, Robert D. Chalgren and Carl L. Anderson
Michigan Technological Univ.

The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL

International Off-Highway & Powerplant Congress & Exposition
Milwaukee, Wisconsin
September 11-13, 2000

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-5760

ISSN 0148-7191

Printed in USA

2000-01-2573

Noise and Emission Reduction Strategies for a Snowmobile

Scott A. Miers, Robert D. Chalgren and Carl L. Anderson
Michigan Technological Univ.

ABSTRACT

The following paper discusses alternative strategies for reducing noise and emission production from a two-stroke snowmobile. Electric, two-stroke and four-stroke solutions were analyzed and considered for entry in the Clean Snowmobile Challenge (CSC) 2000. A two-stroke solution was utilized primarily due to time constraints. Complete snowmobile competition results are provided. The electric solution, while the most effective at reducing emissions, is negatively impacted by weight and cost. A modified two-stroke solution, limited by cost and complexity, does not provide the required improvements in emissions. A four-stroke solution reduces noise and emissions and provides an acceptable trade-off between noise, emissions, performance and cost.

INTRODUCTION

Snowmobile use in environmentally sensitive areas has caused significant controversy amongst several key groups of people. Environmental impact studies have shown that snowmobiles emit a significant amount of pollution and produce noise levels that exceed those of common transportation vehicles [1, 4].

Conventional snowmobiles are powered by two-stroke engines which are designed primarily for optimum performance rather than minimal emission and noise production. With increased awareness on emission and noise sources, snowmobile manufacturers are being asked to incorporate new technology to reduce pollution production.

The Clean Snowmobile Challenge (CSC) was created to develop a snowmobile that could be used to help solve the controversy surrounding snowmobile use in environmentally sensitive areas. CSC 2000 is a collegiate design competition that requires student teams to re-engineer an existing snowmobile, in approximately eight months, for reduced emission and noise production while maintaining or improving the performance characteristics of the original snowmobile. The final designs must be cost effective, durable, and attractive to rental fleet operators. The snowmobiles are tested in a week-long, head-to-head competition between the participating universities in Jackson, WY. Scheduled events include: emission testing, noise measurement, acceleration, hill climb, cold start performance, fuel economy/range, and oral/written reports (including cost and feasibility).

A comprehensive analysis of a conventional snowmobile was conducted to locate the largest source of noise and emission production. Noise testing performed at the Keweenaw Research Center, to locate the major sources of noise on a 500 cc snowmobile, is summarized in table 1.

Table 1: 500 cc Snowmobile Sound Pressure Measurements

Measurement Location	Pressure Level
Exhaust	101 dBA
Track	97 dBA
Engine	91 dBA

Further testing of two snowmobiles provided additional information concerning the largest noise source and location, Figure 1.

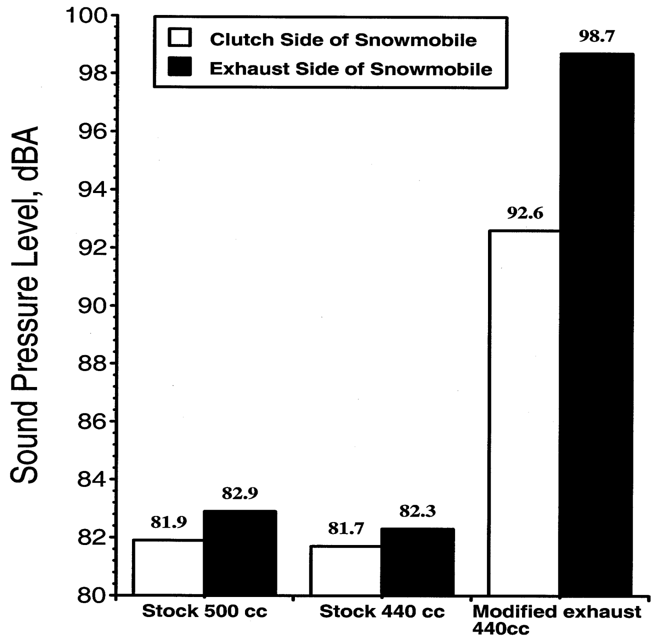

Figure 1. Noise production from two stock snowmobiles and a modified, high performance snowmobile.

The powertrain was identified as the major source and became the main focus of re-design and modification for the new snowmobile.

POWERTRAIN ALTERNATIVES

Three powertrain alternatives were researched with considerations for cost, effectiveness of emissions reduction, durability and performance. An electric solution provides a 100% reduction in emission production as tested at the competition and a significant reduction in powertrain noise, as compared to a conventional snowmobile. A four-stroke solution provides an acceptable power-to-weight ratio while significantly reducing emission and noise production, as compared to two-stroke engines. A two-stroke solution most closely resembles a conventional snowmobile and provides a high power-to-weight ratio solution which riders have come to expect.

ELECTRIC SOLUTION

An electric driven snowmobile would eliminate emission production and reduce noise production significantly. This would appear to be the best solution for the proposed competition, however, technology is yet to provide lightweight, cost effective components.

Preliminary calculations for battery power, performance and weight were conducted for a fully electric powertrain solution. The maximum speed of 48 kilometers per hour was the design point for the snowmobile. Though this was a decrease in maximum speed of most conventional snowmobiles, it was believed to be fast enough for park service and touring type applications. The power equation used was:

$$P_{Total} = P_{Friction} + P_{Aerodynamic}$$

where:

P_{Total} = power required to transport vehicle at constant velocity.

$P_{Friction}$ = power required to overcome friction, assumed to vary linearly with velocity.

$P_{Aerodynamic}$ = power required to overcome aerodynamic effects, assumed to vary with the square of the velocity.

The result was a power requirement of approximately 15,000 watts to transport a conventional 230 kg snowmobile, with an 80 kg rider, at 48 k.p.h.

The acceleration and endurance events were used for calculating required peak power and energy capacity requirements of the batteries. The required time to accelerate from 0 to 48 kph was calculated to be approximately 2 seconds, assuming a motor and drive-train efficiency of 75% [2]. Maintaining a speed of 48 kph for approximately 3.5 hours, to complete the 160 km endurance event, required 25, 12 volt batteries weighing over 450 kg. In addition, the weight of a 15 kW electric motor and necessary control systems add to the overall weight of the proposed solution. Preliminary estimates predict 450-650 kg of weight being added to a conventional snowmobile to incorporate an electric drive.

Due to the significant amount of additional weight and high cost of components, the electric solution is not, at this time, a practical alternative to a two-stroke powertrain. Improvements in energy storage devices and reduced costs would be necessary to make the electric powertrain a viable option for reducing noise and emission production in future snowmobiles.

FOUR-STROKE SOLUTION

A four-stroke solution was investigated that would provide the necessary emissions reductions while maintaining performance and minimizing additional weight. Noise reductions are expected to occur naturally, due to 1/2 the power cycles per a given engine speed, as compared to a two-stroke engine.

Emissions Reduction

Numerous studies have shown that four-stroke engines produce significantly lower emissions than two-stroke engines, Figure 2 [3].

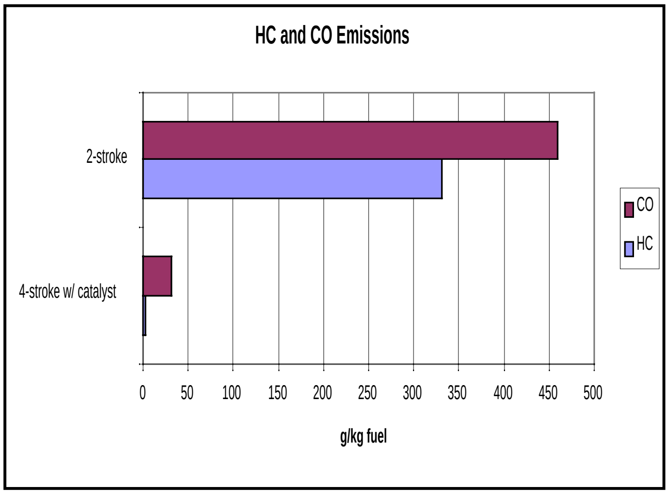

Figure 2. CO and HC production comparison for two-stroke and four-stroke engines.

The specific four-stroke engine that was chosen for the solution was developed for a limited production, sport-touring motorcycle that meets CARB II emission standards. The engine is factory equipped with electronic fuel injection (EFI), exhaust air injection, and three-way exhaust catalyst. Current emission levels are reported in table 2. Rated fuel economy is reported as 18.5 kilometers per liter [4].

Table 2: Specific Four-Stroke Emissions

Emission Product	Quantity (g/km)
UHC	1.1g/km
CO	7.0g/km

Four-stroke engines control the air exchange process through the use of valves. This control creates an inherent reduction in emission production compared to two-strokes. Further reductions are achieved through the addition of several components on the particular chosen engine. Precise control of the air/fuel delivery ratio to the engine is necessary to obtain the optimum conversion efficiency in the catalyst, as shown in Figure 3.

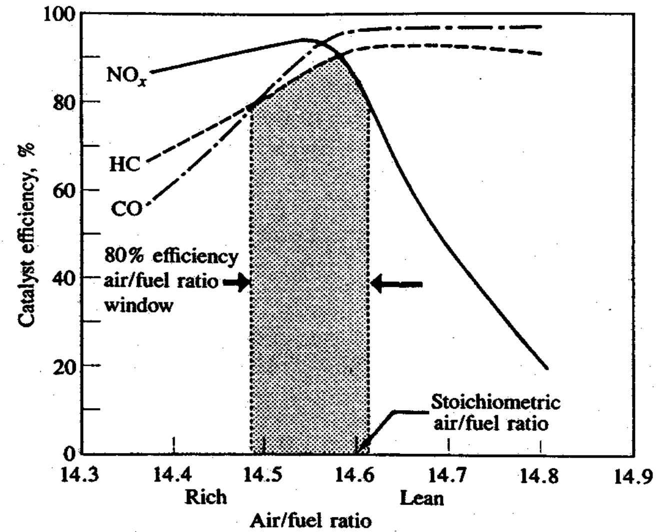

Figure 3. Air/fuel ratio effect on conversion efficiency within the catalytic converter.

Electronic fuel injection provides the necessary control of the air/fuel ratio. The narrow window of 80% conversion efficiency cannot be consistently maintained by conventional carburetors [5]. In addition, EFI provides nearly instantaneous, fuel-delivery compensation for barometric pressure changes, temperature changes and cold start-up. In a verification test performed by Southwest Research Institute, a sea-level calibrated two-stroke engine was tested at elevation-type conditions. The test showed that hydrocarbons increased by 31%, carbon monoxide increased by 14%, particulate matter increased by 27%, and fuel consumption increased by 16% while power decreased by 19% [6].

The four stroke engine also incorporates secondary air injection. The exhaust emission control system introduces filtered air into the exhaust gases at the exhaust port. Fresh air is drawn into the exhaust port through a control valve. This charge of fresh air promotes burning of the unburned exhaust gases, HC and CO, and aids in their conversion to CO_2 and H_2O [7].

Fuel Choice

A major source of emissions from internal combustion engines is the incomplete combustion of fuel. Oxygenated fuel, such as 10% ethanol blend (E10) can substantially reduce overall emission production and will be the preferred fuel for either the four-stroke or two-stroke solution. A 10% ethanol blended fuel contains oxygen which promotes a more complete combustion of fuel, resulting in a 25-30% reduction in CO emissions, as compared to conventional 91 octane gasoline. This in turn should lead to an overall reduction in HC emissions as well. In addition, the 10% ethanol blended fuel can reduce CO_2 production by 6-10% [8].

Power Retention

The four-stroke engine is a 781 cc liquid cooled 90^o V-4 configuration which utilizes dual overhead camshafts and four-valve heads. The four-stroke engine produces a broader power band in comparison to a typical snowmobile two-stroke engine, Figure 4 [9, 10], which provides easier tuning of the drive system and increased rider satisfaction through better driveability.

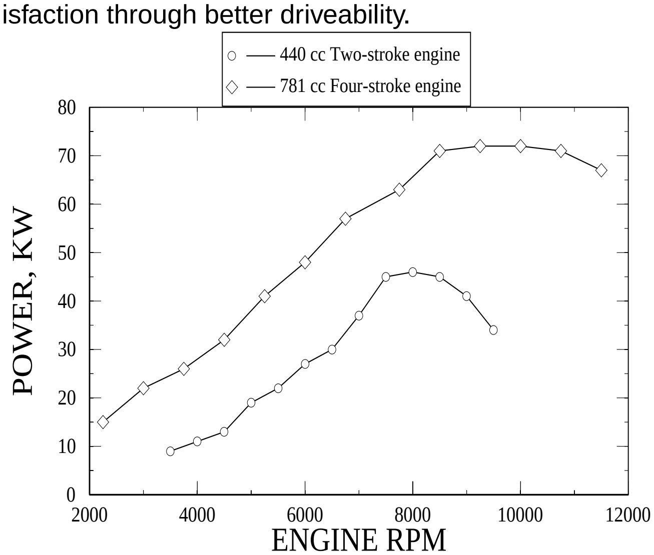

Figure 4. Power output comparison for typical 440 cc two-stroke engine and 781 cc four-stroke engine.

Narrow power bands, of less than 500 rpm, are difficult to tune and provide less than optimal performance when trail conditions, temperature and altitude change. Snowmobiles are often required to operate under ever changing conditions. It is not uncommon to operate a snowmobile through a 20-30 degree temperature change and a 2,000 - 3,000 meter elevation change in a single ride. A wide, usable power curve provides increased operating range and efficiency for the drive system.

Noise Control

A reduction in exhaust noise will occur through the replacement of the two-stroke engine with a four-stroke engine due to the reduced frequency of the power cycles. A four-stroke engine has a combustion cycle every 720 degrees, whereas a two-stroke engine has a combustion cycle every 360 degrees. In addition to the natural reduction in noise, a liquid cooled engine was desired due to the natural absorption capability of the surrounding water. The water jacket provides a barrier to internal engine noise and provides a consistent operating temperature for the engine. While particulate matter production may increase slightly with a liquid-cooled engine as compared to a fan-cooled engine, gasoline or E10 powered four-stroke engines are not known for high particulate production.

Installation Concerns

The chosen four-stroke engine is not designed for direct installation into a conventional snowmobile chassis. In addition, CSC 2000 rule 4.3.2 stated, “The snowmobile must be propelled with a variable ratio belt transmission” [11]. Three months of design time were dedicated to designing a mounting system for the engine and the drive system to incorporate a continuously variable transmission (CVT). Due to time constraints and reliability concerns, the four-stroke engine installation was moved to a two year design process. A senior design team has designed and modeled a complete chassis around the four-stroke engine. Additionally, the drive system components will be manufactured at a specialty fabrication shop to ensure high quality components.

TWO-STROKE SOLUTION

A modified two-stroke solution, similar to a conventional snowmobile engine, was investigated as a third option. Two strokes benefit from a lightweight, high horsepower design that makes them attractive to small recreational vehicles. Their excessive noise and emission production requires significant modifications to existing designs to meet competition or some legal regulations.

Emissions Reduction

Two-stroke engines can benefit from some of the same emissions reducing technology that four-stroke engines use. Exhaust catalyst and secondary air injection are two techniques that are currently in use to help reduce two-stroke emissions. In addition, direct fuel injection can reduce emissions levels to a level that is comparable to uncontrolled four-stroke units [12]. However, current direct fuel injection systems are complex, expensive and remain to be proven reliable. Direct injection was not practical, from a one year student design perspective, as our goal was to design a snowmobile within reasonable cost limits and provide a reliable solution in an eight month time frame.

It was believed that secondary air injection and a properly designed exhaust catalyst could be implemented on a conventional two-stroke snowmobile engine which produce reductions in emissions. There was concern about providing enough air volume for secondary air injection to be effective. In addition, introducing cold air into the exhaust pipe may slow down or even prevent the oxidation reactions taking place in the exhaust. Catalysts may overheat in a two-stroke exhaust due to an overload from the excessive amounts of unburned hydrocarbons and carbon monoxide. Proper cooling and insulating of the catalyst would be required to prevent external ignition and component failure.

TWO STROKE DEVELOPMENT

Due to time constraints and the decision to move the four-stroke engine to a two-year design, development began for a two-stroke solution. Locating a high power, lightweight, liquid cooled two-stroke engine with provisions for CVT drive was the major goal. A 500 cc liquid-cooled engine was chosen as the replacement. A catalyst was custom designed from an automobile unit and sized to allow installation into the snowmobile exhaust system. The design was a partial flow-through type which would not create a significant restriction in the exhaust flow.

A commercially available air pump was purchased to supply the secondary air into the exhaust pipe. Further development of the air injection system found that the pump did not supply enough volume of air and thus was not very effective.

COMPETITION RESULTS

The Michigan Tech Clean Snowmobile Team competition results are provided in table 3.

Our first place finish in the hill climb event was exciting. We were the only team to reach the top and did so in record time. The acceleration event was a very close second with .045 seconds separating first and second. Carbon monoxide production was reduced 35% compared to the control vehicle, which can be attributed to proper altitude calibration and the use of E10 fuel. The 18% increase in unburned hydrocarbons was not expected and is of concern to the team. No explanation for the increase in UHC is available at this time. The noise target was missed by .4 dBA. Noise reduction modifications were made to the stock snowmobile muffler but testing was limited and optimization of the design was not achieved. The fuel economy was significantly decreased due to an improperly routed gas tank vent line which allowed siphoning of the fuel once the snowmobile was in motion. During the handling event, the crankshaft failed which did not allow us to finish the event.

Table 3: Competition Results

Event	MTU Results	Control Vehicle Results	Place (out of 7)
Emission Reduction (increase)	CO: 35% HC: (18%)	CO: 0% HC: 0%	tied for 2nd
Noise	75.4 dBA	75.0 dBA	tied for 3rd
Hill climb	1 min. 0.4 seconds	---	1st
Fuel Economy	10.636 gallons	7.366 gallons	4th
Handling	DNF	---	tied for 5th
Acceleration	7.286 seconds	7.841 seconds	2nd
Design Report	45 points	---	7th
Static Display	30 points	---	5th
Oral Presentation	44 points	---	7th
Overall Result			**4th**

CONCLUSIONS

The preferred strategy, for addressing the major goals of the competition, is to install a four-stroke engine into a snowmobile chassis. An engine with substantial power, significant emission control and increased fuel efficiency is being prepared for the CSC 2001 competition. Additional weight concerns, due to implementing the four-stroke engine, can be off-set through the use of composite materials in the chassis and suspension along with implementing simplified drivetrain components.

We believe the future of snowmobiling will be well-served by four-stroke engines, providing significant reductions in emissions and noise while still providing the performance, driveability and handling consumers expect.

ACKNOWLEDGMENTS

We wish to acknowledge the major SAE CSC 2000 competition sponsors. They are: Montana Department of Environmental Quality, U.S. Environmental Protection Agency, Teton County Wyoming, WestStart, Conoco, U.S. Department of Energy, Tenneco Automotive, Town of Jackson Wyoming, and Wyoming Business Council.

In addition, we would like to thank our team sponsors for support and professional assistance. They are: Michigan Tech Department of Mechanical Engineering-Engineering Mechanics, Michigan Tech College of Engineering, Keweenaw Research Center, Recreational Dynamics, Hayes Polaris, Crazy Mountain Motorsports, Camoplast, Gates Belts and Hoses, Exhaust Gas Technologies, Comet Industries, Chopper City, and Amsoil.

REFERENCES

1. Snook-Fussell, L.M., “Exposure of Snowmobile Riders to Carbon Monoxide.” *Park Science*. 17:1. 1997.

2. Piper, James W., “Powertrain.” Electric Auto Association of Phoenix. 1998.

3. Bishop, G.A., Stedman, D.H., “An In-Use Snowmobile Emission Survey in Yellowstone National Park.”, *Environmental Science and Technology*, Vol. 33, No. 21, 1999.

4. California Air Resources Board, “The California Low-Emissions Vehicle Regulations.”, www.arb.ca.gov, 1998.

5. Heywood, John B., *Internal Combustion Engine Fundamentals*. McGraw-Hill, New York, 1988.

6. Haines, Howard. The Snowmobile Dilemma, or, Who Spilled What in the Refrigerator vs. Who’s Going to Clean It Up?, Montana Department of Environmental Quality, 1999.

7. Honda Service Manual, *VFR 800FI Interceptor*. Honda Motor Company, Ltd. Tokyo, Japan, 1998.

8. Canadian Renewable Fuels Association, Guelph, Ontario, Canada. (519) 767-0431, www.greenfuels.org.

9. Motorcycle Online. “1998 Honda VFR 800FI Interceptor.” www.motorcycle.com/mo/mchonda/98vfr800.html.

10. PSI Performance, *Snow Catalog*. Wild Rose, WI, 1993.

11. Fussell, Lori M., Paddleford, Bill, “The Clean Snowmobile Challenge 2000 Rules.” 1999.

12. Mercury Marine, “Direct Injection Two-Stroke and Four-Stroke Outboards.” 1999.

CONTACT

Scott A. Miers. Engineering Mechanics Graduate Student, Michigan Technological University, Houghton, MI. 49931. E-mail: samiers@mtu.edu